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Optical Microscopy to Study Crystal Nucleation in Polymers Using a Fast Scanning Chip Calorimeter for Precise Control of the Nucleation Pathway

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Abstract

© 2017 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim Polarized-light optical microscopy (POM) is applied for investigation of homogeneous crystal nucleation in polymers, using the advantage of precise control of the nucleation pathway by application of fast scanning chip calorimetry (FSC). In the first part of this paper, homogeneous crystal nucleation in glassy poly (l-lactic acid) (PLLA) employing Tammann's two-stage crystal nuclei-development method is highlighted. PLLA samples of different nucleation history are prepared in an FSC, and then POM micrographs are studied regarding the effect of time and temperature of annealing the glass on the number of spherulites, which developed in the growth-stage at higher temperature. The obtained images provide ultimate evidence about the validity of Tammann's approach for obtaining information about the kinetics of homogeneous crystal nucleation using calorimetry, when quantifying the number of nuclei by the enthalpy of crystallization during their growth to crystals in the development stage. In the second part of this study, information about the semicrystalline morphology of samples of poly(butylene terephthalate) and polyamide 66 crystallized at different supercooling using FSC is presented. POM analysis confirms the origin of the frequently observed bimodal temperature-dependence of the crystallization rate as being caused by different mechanisms of crystal nucleation, resulting in qualitatively different structures.

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Keywords

crystallization, fast scanning chip calorimetry, nucleation, polarized-light optical microscopy, semicrystalline morphology

References

[1] A. Toda, R. Androsch, C. Schick, Polymer 2016, 91, 239.
[2] C. Schick, R. Androsch, in Fast Scanning Calorimetry (Eds: C. Schick, V. Mathot), Springer, Switzerland 2016, pp. 463–535.
[3] R. Androsch, C. Schick, Adv. Polym. Sci. 2017, 276, 257.
[4] C. Schick, R. Androsch, J. W. P. Schmelzer, J. Phys.: Condens. Matter 2017, 29, 453002.
[5] R. Androsch, A. M. Rhoades, I. Stolte, C. Schick, Eur. Polym. J. 2015, 66, 180.
[6] Q. Zia, H.-J. Radusch, R. Androsch, Polym. Bull. 2009, 63, 755.
[7] Q. Zia, R. Androsch, H.-J. Radusch, J. Appl. Polym. Sci. 2010, 117, 1013.

[8] E. Zhuravlev, J. W. P. Schmelzer, B. Wunderlich, C. Schick, Polymer 2011, 52, 1983.
[9] Y. Furushima, S. Kumazawa, H. Umetsu, A. Toda, E. Zhuravlev, A. Wurm, C. Schick, J. Appl. Polym. Sci. 2017, 134, 44739.
[10] R. Androsch, H. M. N. Iqbal, C. Schick, Polymer 2015, 81, 151.
[11] G. Tammann, Z. Phys. Chem. 1898, 25, 441.
[12] G. Tammann, E. Jenckel, Z. Anorg. Allg. Chem. 1930, 193, 76.
[13] M. L. F. Nascimento, V. M. Fokin, E. D. Zanotto, A. S. Abyzov, J. Chem. Phys. 2011, 135, 194703.
[14] K. H. Illers, Kolloid Z. Z. Polym. 1971, 245, 393.
[15] L. Bove, C. D'Aniello, G. Gorrassi, L. Guadagno, V. Vittoria, Polym. Bull. 1997, 38, 579.
[16] M. S. Sánchez, V. B. F. Mathot, G. Vanden Poel, J. L. G. Ribelles, Macromolecules 2007, 40, 7989.
[17] F. Hernández Sánchez, J. Molina Mateo, F. J. Romero Colomer, M. Salmerón Sánchez, J. L. Gómez Ribelles, J. F. Mano, Biomacromolecules 2005, 6, 3283.
[18] F. De Santis, R. Pantani, G. Titomanlio, Thermochim. Acta 2011, 522, 128.
[19] A. Wurm, E. Zhuravlev, K. Eckstein, D. Jehnichen, D. Pospiech, R. Androsch, B. Wunderlich, C. Schick, Macromolecules 2012, 45, 3816.
[20] E. Zhuravlev, J. W. P. Schmelzer, A. Abyzov, V. Fokin, R. Androsch, C. Schick, Cryst. Growth Des. 2015, 15, 786.
[21] R. Androsch, C. Schick, J. W. P. Schmelzer, Eur. Polym. J. 2014, 53, 100.
[22] I. Stolte, R. Androsch, M. L. Di Lorenzo, C. Schick, J. Phys. Chem. B 2013, 117, 15196.
[23] R. Androsch, C. Schick, A. M. Rhoades, Macromolecules 2015, 48, 8082.
[24] R. Androsch, M. L. Di Lorenzo, Macromolecules 2013, 46, 6048.
[25] R. Androsch, M. L. Di Lorenzo, Polymer 2013, 54, 6882.
[26] M. C. Righetti, M. Gazzano, M. L. Di Lorenzo, R. Androsch, Eur. Polym. J. 2015, 70, 215.
[27] M. Pyda, E. Nowak-Pyda, J. Heeg, H. Huth, A. A. Minakov, M. L. Di Lorenzo, C. Schick, B. Wunderlich, J. Polym. Sci., Polym. Phys. 2006, 44, 1364.
[28] J. E. K. Schawe, J. Therm. Anal. Calorim. 2014, 116, 1165.
[29] A. M. Gohn, A. M. Rhoades, N. Wonderling, T. Tighe, R. Androsch, Thermochim. Acta 2017, 655, 313.
[30] S. Piccarolo, J. Macromol. Sci., Phys. 1992, B31, 501.
[31] Q. Zia, R. Androsch, H.-J. Radusch, S. Piccarolo, Polymer 2006, 47, 8163.
[32] D. Mileva, R. Androsch, H.-J. Radusch, Polym. Bull. 2009, 62, 561.
[33] D. Mileva, I. Kolesov, R. Androsch, Colloid Polym. Sci. 2012, 290, 971.
[34] I. Kolesov, D. Mileva, R. Androsch, Polym. Bull. 2014, 71, 581.
[35] A. Mollova, R. Androsch, D. Mileva, C. Schick, A. Benhamida, Macromolecules 2013, 46, 828.
[36] A. Keller, J. Polym. Sci. 1955, 17, 291.
[37] H. D. Keith, F. J. Padden, J. Appl. Phys. 1963, 34, 2400.
[38] A. S. Vaughan, Sci. Prog. 1992, 76, 1.
[39] J. H. Magill, J. Mater. Sci. 2001, 36, 3143.
[40] D. M. Gezovich, P. H. Geil, Polym. Eng. Sci. 1968, 8, 202.
[41] C. C. Hsu, P. H. Geil, H. Miyaji, K. Asai, J. Macromol. Sci., Phys. 1983, B22, 489.
[42] G. S. Y. Yeh, P. H. Geil, J. Macromol. Sci., Phys. 1967, B1, 235.
[43] T. Ogawa, M. Miyaji, K. Asai, J. Phys. Soc. Jpn. 1985, 54, 3668.
[44] Z. G. Wang, B. S. Hsiao, S. Srinivas, G. M. Brown, A. H. Tsou, S. Z. D. Cheng, R. S. Stein, Polymer 2001, 42, 7561.
[45] Q. Zia, R. Androsch, H.-J. Radusch, E. Ingolicˇ, Polym. Bull. 2008, 60, 791.
[46] A. Schaper, R. Hirte, C. Ruscher, R. Hillebrand, E. Walenta, Colloid Polym. Sci. 1986, 264, 649.
[47] D. Mileva, R. Androsch, E. Zhuravlev, C. Schick, Polymer 2012, 53, 3994.
[48] J. Varga, J. Mater. Sci. 1992, 27, 2557.
[49] F. J. Padden, H. D. Keith, J. Appl. Phys. 1959, 30, 1479.
[50] M. B. O. Idrissi, B. Chabert, J. Guillet, Makromol. Chem. 1986, 187, 2001.
[51] E. J. Roche, R. S. Stein, E. L. Thomas, J. Polym. Sci., Polym. Phys. 1980, 18, 1145.
[52] R. S. Stein, A. Misra, J. Polym. Sci., Polym. Phys. 1980, 18, 327.
[53] M. Gahleitner, C. Grein, S. Kheirandish, J. Wolfschwenger, Int. Polym. Proc. 2011, 26, 1.
[54] D. J. Blundell, A. Keller, A. J. Kovacs, J. Polym. Sci., Polym. Lett. 1966, 4, 481.

[55] B. Fillon, B. Lotz, A. Thierry, J. C. Wittmann, J. Polym. Sci., Polym. Phys. 1993, 31, 1395.

[56] K. Jariyavidyanont, R. Androsch, C. Schick, Polymer 2017, 124, 274.

[57] A. M. Rhoades, N. Wonderling, A. Gohn, J. Williams, D. Mileva, M. Gahleitner, R. Androsch, Polymer 2016, 90, 67.

[58] A. M. Rhoades, N. Wonderling, C. Schick, R. Androsch, Polymer 2016, 106, 29.

[59] D. Baeten, V. B. F. Mathot, T. F. Pijpers, O. Verkinderen, G. Portale, P. Van Puyvelde, B. Goderis, Macromol. Rapid. Commun. 2015, 36, 1184.

[60] D. Baeten, D. Cavallo, G. Portale, R. Androsch, V. Mathot, B. Goderis, in Fast Scanning Calorimetry (Eds: C. Schick, V. Mathot), Springer International Publishing, Cham 2016, pp. 327.

[61] M. Rosenthal, D. Doblas, J. J. Hernandez, Y. I. Odarchenko, M. Burghammer, E. Di Cola, D. Spitzer, A. E. Antipov, L. S. Aldoshin, D. A. Ivanov, J. Synchrotron. Radiat. 2014, 21, 223.

[62] A. P. Melnikov, M. Rosenthal, A. I. Rodygin, D. Doblas, D. V. Anokhin, M. Burghammer, D. A. Ivanov, Eur. Polym. J. 2016, 81, 598.

[63] P. Cebe, X. Hu, D. L. Kaplan, E. Zhuravlev, A. Wurm, D. Arbeiter, C. Schick, Sci. Rep. 2013, 3, 1130.

[64] L. Wei, J. Jiang, M. Shan, W. Chen, Y. Deng, G. Xue, D. Zhou, Rev. Sci. Instrum. 2014, 85, 074901.